Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

Nature Environment and Pollution Technology An International Quarterly Scientific Journal	ISSN: 0972-6268	Vol. 10	No. 2	pp. 225-228	2011

Original Research Paper

Efficacy of Electrocoagulation in Treatment of Textile Wastewater Containing Basic Red Dye Using Iron Electrodes

Shilpi Sharma, Sanjay Mathur and Rahul Sharma
Department of Civil Engineering, Malviya National Institute of Technology, Jaipur-302 017, Rajasthan, India

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 20-8-2010
Accepted: 29-9-2010

Key Words:
Electrocoagulation
Textile wastewater
Iron electrodes
COD removal

ABSTRACT

Wastes released from textile industries may adversely affect environment and human health as they possess toxic elements. Many methods have been used to decolorize such effluents. This study was performed to investigate the behaviour of COD removal pattern from synthetic wastewater containing Basic red dye using electrocoagulation process. The study focused on the effect of voltage, dye concentration, salt concentration, initial pH of wastewater, sacrificial weight loss of electrodes, duration of current flow, etc. on COD removal rate. Simple electrochemical cell was prepared using iron electrodes. The effectiveness of the method was determined by measuring percentage of COD removal. It was found that highest COD removal was achieved at 10V after an operating time of 40-50 minutes beyond which substantial increment in COD removal rate was not obtained. The efficiency of COD removal for 150mg/L dye concentration at 10V was around 70%. It is also deduced that plain electrocoagulation far exceeds the efficiency of any combinational process like chemical coagulation followed by electrocoagulation or vice versa.

INTRODUCTION

The day-to-day human activities and industrial revolution have influenced the flow and storage of water and the quality of available freshwater. Many industries like textile, refineries, chemical, plastic and food-processing plants produce wastewaters characterized by a perceptible content of organics (e.g., phenolic compounds) with strong colour. Textile industries consume large volumes of water and chemicals for wet processing of textiles. The chemical reagents used are very diverse in chemical composition, ranging from inorganic compounds to polymers and organic products. Conventional methods for dealing with textile wastewater consist of various combinations of biological, chemical and physical methods (Babuna et al. 1999, Slokar et al. 1998). Textile wastewater is well known with its high chemical oxygen demand, strong colour, large amount of suspended solids, variable pH, salt content high temperature and the variation of wastewater characteristics. Therefore, the treatment systems combined with physical, biological and chemical methods become inefficient for the effective treatment of industrial textile wastewater (Tsai et al. 1997, Naumczyk et al. 1996).

As environmental regulations become stringent, new and novel processes for efficient treatment of various kinds of wastewater at relatively low operating cost are needed. Furthermore, treatment cost of textile waste effluents has been escalating fairly rapidly in recent years. On the other hand, due to the scarcity of space, extremely high land cost and the complexity of handling chemicals in countries like India, a simple and efficient treatment process for the textile wastewater is essentially necessary.

One of promising methods for treating hard-to-treat wastewater streams is the electrochemically based treatment method. Electrochemical processes (electrolysis and electrocoagulation) have been successfully demonstrated for removing pollutants in various industrial wastewaters (Vlyssides et al. 2001, Tsai et al. 1997, Naumczyk et al. 1996). Removal mechanisms reported in the electrolysis process generally include oxidation, reduction, decomposition, whereas the mechanisms in the electrocoagulation process include coagulation, adsorption, precipitation and flotation (Vlyssides et al. 1999, Grimm et al. 1998, Rajeshwar et al. 1994).

Electrocoagulation: Electrocoagulation utilizes direct current to cause sacrificial electrode ions to remove undesirable contaminants either by chemical reaction and precipitation or by causing colloidal materials to coalesce and then be removed by electrolytic flotation. The electrochemical system has proven to be able to cope with a variety of wastewaters. Electrocoagulation utilizes aluminium or iron anodes to produce aluminium or iron hydroxide flocs by reaction at the anodes followed by hydrolysis. The electrocoagulation is a simple and efficient method for the treatment of water and wastewater. It has not been widely accepted because of high initial capital costs as compared to other treatment technologies.

Electrocoagulation involves the generation of flocs *in situ* by dissolving electrically either aluminium or iron ions from respectively aluminium or iron electrodes. The metal ion generation takes place at the anode, hydrogen gas is released from the cathode. The hydrogen gas helps to float the flocculated particles out of the water. This process is called electroflocculation. The electrodes can be arranged in a monopolar or bipolar mode. The materials can be aluminium or iron in plate form or packed form of scraps such as steel turnings, millings, etc.

The nascent Al^{3+} or Fe^{2+} ions are very efficient coagulants. The hydrolysed aluminium ions can form large networks of Al-O-Al-OH that can chemically adsorb pollutants such as F^- (Shen et al. 2003). Aluminium is usually used for water treatment and iron for wastewater treatment.

The advantages of electrocoagulation include high particulate removal efficiency, compact treatment facility, relatively low cost and possibility of complete automation. Fe^{3+}(aq) and $3OH^-$ ions generated react to form various monomeric species. Electrogenerated ferric ions may form monomeric ions, ferric hydroxo-complexes with hydroxide ions and polymeric species, depending on the pH range. These are: $FeOH^{2+}$, $Fe(OH)_2^+$, $Fe_2(OH)_2^{4+}$, $Fe(OH)_4^-$, $Fe(H_2O)_2^+$, $Fe(H_2O)_5OH^{2+}$ $Fe(H_2O)_4(OH)_2^+$, $Fe(H_2O)_8(OH)_2^{4+}$, $Fe_2(H_2O)_6(OH)_4^{2+}$, which transform finally into $Fe(OH)_3$ (Pykhteev 1999).

The problem of the textile and dyeing industry is on an exponential rate of increase in the Asian countries due to the continuous shifting of the manufacturing business in these industries towards the third world countries, especially India and the ever stringent standards posed by the Pollution Control Boards. The proposed work of study is thus an attempt to analyse the efficiency of the process of electrocoagulation with respect to various parameters like pH, COD and other chemical parameters from the dyeing and textile industry effluents especially with respect to basic red dye.

EXPERIMENTAL SETUP

The study of freshly prepared synthetic waste was conducted in a bench-scale electrochemical system for COD removal. The system consists of a DC power supply, a power control system and an electrochemical reactor. Variations in COD removal with respect to voltage, time duration, concentration of dye, pre and post usage of chemical coagulation on electrocoagulation were analysed.

Table 1: Composition of synthetic dye wastewater used.

Chemicals	Concentration (mg/L except for liquid detergent)
Dye	150
NaCl	15
Hydrolyzed starch	2.78
Ammonium sulphate	5.56
Disodium hydrogen phosphate	5.56
Liquid detergent	5-6 drops

The experimental set up consisted of a beaker of 1.0 litre as a reactor to hold a sample of 900 mL. A pair of steel electrode cylindrical rods as anode and cathode, each with an active surface area of 44 cm^2 was arranged at a spacing of 3 cm, and connected to an external power source. A DC linear power source (Testronix, 230 V DC regulated power supply), having an ammeter and a volt meter to read the values of current and voltage, was used.

During the process, flocs were formed which float at the surface of sample. pH and COD were measured before the process was started and after an interval of consecutive 10 minutes till 80 minutes. An upper limit of 80 minutes was selected as the values of these two parameters got stabilized after this time interval. The COD was measured with UV/VIS spectrophotometer manufactured by Schimadzu model 6800 at 600 nm. COD removal was expressed as a percentage due to the variation in the initial COD value of sample.

Table 1 gives composition of synthetic dye wastewater used for experimental purpose. The solution was heated at 80°C for 1.5 hours which was then left for cooling till room temperature.

RESULTS AND DISCUSSION

Firstly, the results were analysed to determine whether the energy supplied in the form of electric current is solely used for electrocoagulation or some amount of it has been used in partial oxidation of the dye molecules. For this purpose, COD of influent was measured and current was passed through it for 60 minutes at different voltages. The sample was then kept undisturbed and sludge was allowed to settle down. The COD of sludge and supernatant were determined separately and the combined COD of the effluent was calculated with due consideration to volume of sludge and supernatant. The results are tabulated in Table 2. The results showed that almost 95 % of the COD was accounted for the process involved of separation and not oxidation.

COD removal at different voltages: The first test was performed to optimize the voltage for maximum COD removal. Fig. 1 represents the effect of applied voltage on COD removal rates at 5, 10, 15, 20, 25 and 30 V. At 5 V, after passing current for 30 minutes into the solution, about 36 % COD removal was achieved which decreases as we move from 5 V to 7 and 8V. From 8V onwards a rise is observed in COD removal rate which continue growing at 10V also. As we move on from 10V to 15V, a decrement in the COD removal was observed which continues till 20V. At 25V again, a rise in COD removal rate was achieved which then decreases at 30V. Nearly same trend is followed for different contact

Table 2: COD of influent and effluent.

S. No.	Applied voltage (V)	Measured COD of influent (mg/L)	COD of effluent (mg/L)		Volume of effluent (mL)		Calculated COD of effluent (mg/L)
			Supernatant	Sludge	Supernatant	Sludge	
1	10	364.50	279.6	523.1	670	230	341.8
2	15	338.40	228.4	566.7	685	215	309.2
3	20	326.45	244.4	483.3	695	205	298.8
4	25	341.70	242.7	512.8	685	215	307.2
5	30	417.60	323.7	653.0	680	220	404.2

periods of 40, 50, 60 and 80 minutes respectively. Maximum COD removal was achieved for 10V. The reason behind this may be attributed to the fact that maximum flocs are formed at 10V and further increase in voltage may destabilize the already formed flocs due to which COD removal efficacy is decreased.

COD removal for different contact periods: Colour removal efficiency depends on the concentrations of ions produced. When the contact period is increased, an increase occurs in ions concentration. Fig. 2 represents the variations achieved in COD removal rates with respect to different voltage and contact periods. It can be concluded that highest COD removal is attained after 40-50 minutes of passing current into the wastewater sample. After 40 minutes there is no significant increment in the rise of COD removal thus further supply of current may weaken the economics of the process.

COD removal at different concentrations of salt: The higher the salt concentration, the greater will be the conductivity of the solution and hence, the flow of the electrons. The experiments were conducted for no salt, 0.5g/L, 1.0 g/L, 1.5 g/L and 2.0 g/L salt concentration. Fig. 3 demonstrate the trends followed. It was observed that as salt concentration is increased, a sharp rise in COD removal rates is observed at 10, 20 and 30 V after which a decrement is registered.

COD Removal at different pH of wastewater: pH is an important chemical parameter for analysing treatment feasibility. Fig. 6 represents the effects of pH of wastewater on COD removal rate. At pH 6.0 best COD removal is achieved for 10V which decreases at 20V and then again rises at 30V. The same trend is observed for pH 7, 8, 9, 10, 11 and 12. It can be concluded that best COD removal is achieved at pH range of 9-11 after which decrement is observed. Thus, to maximize the efficiency of iron electrodes, initial pH should be alkaline as basic dyes have a tendency to precipitate at alkaline pH.

Effect of voltage on sacrificial weight of electrodes: Electrocoagulation produces metal hydroxides as current is passed through them. These flocs tend to coalesce with the dye molecules allowing them to trickle under the force of gravity. The study here was an attempt to investigate the effect of voltage on sacrificial weight of electrodes. For this, two sets were taken as: set I-plain electrocoagulation, and set II-chemical coagulation followed by electrocoagulation.

Fig. 7 represents the effect of voltage on sacrificed weight of electrodes or the amount of metal hydroxides formed. The difference in sacrificed weight at 20 and 30V is not significant. The same pattern is observed for chemical coagulation followed by electrocoagulation. When comparing the two cases it can be seen that a significantly less amount of weight is sacrificed in the set-II which can be credited to the fact

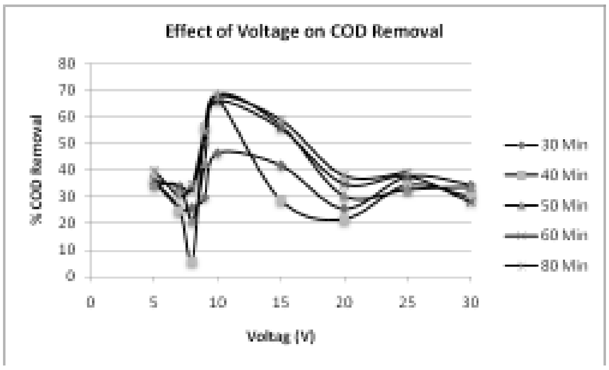

Fig. 1: Effect of voltage on COD removal.

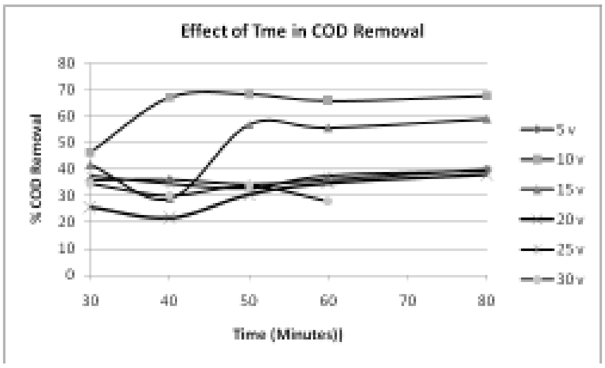

Fig. 2. Effect of time on COD removal.

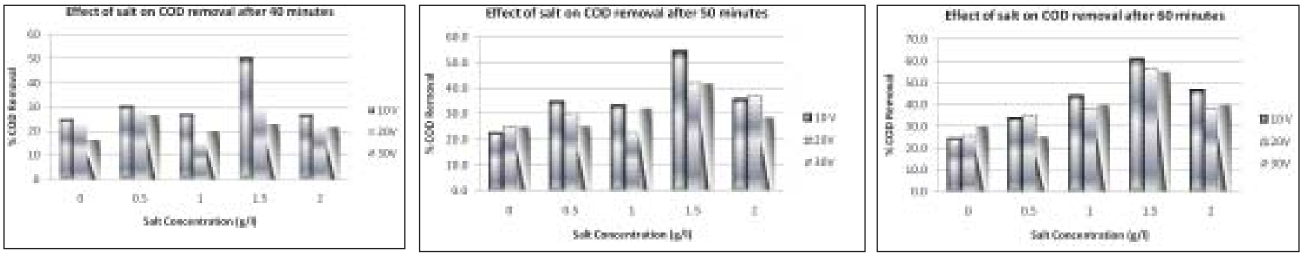

Fig. 3: Effects of salt concentrations on COD removal after 40, 50 and 60 minutes.

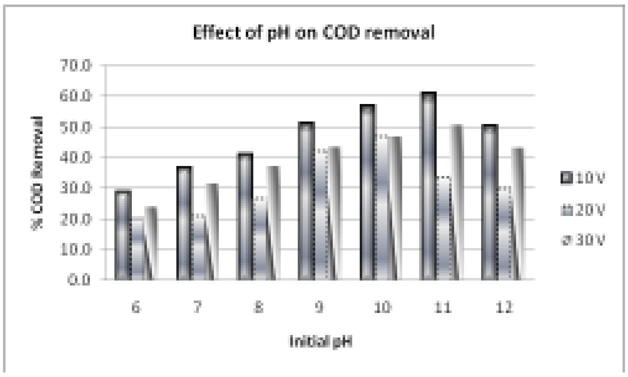

Fig. 4: Effect of pH on COD Removal.

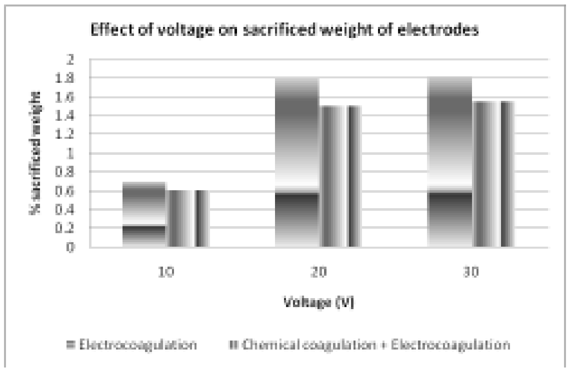

Fig. 5: Effect of voltage on sacrificed weight of electrodes.

that prior chemical coagulation reduces the dye concentration and thus the amount of hydroxides required to reduce the same COD levels. Thus, it can be concluded that plain electrocoagulation has higher degree of weight sacrificed and is more efficient than any combination with chemical coagulation.

CONCLUSION

The electrocoagulation process, performed with iron electrodes was able to remove 65-70% COD from the synthetic wastewaters containing basic red dye having concentration of 150ppm. The maximum COD removal rates were achieved at voltages of around 10V after operating the system for about 40-50 minutes at 1.5 g/L salt concentration. For Basic red dye, the optimum pH range for best COD removal rates ranges from 9-11.

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